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LOW COST SOLAR ARRAY PROJECT

CELL AND MODULE FORMATION RESEARCH AREA

PROCESS RESEARCH OF NON-CZ SILICON MATERIAL

QUARTERLY REPORT NO. 3

September 1, 1982 to November 30, 1982

CONTRACT NO. 955909

The JPL Low-Cost Silicon Array Project is sponsored by the U. S. Department of Energy and forms part of the Solar Photovoltaic Conversion Program to initiate a major effort toward the development of low-cost solar arrays. This work was performed for the Jet Propulsion Laboratory, California Institute of Technology, by agreement between NASA and DOE.

Advanced Energy Systems Division
WESTINGHOUSE ELECTRIC CORPORATION
P. O. Box 10864
Pittsburgh, Pennsylvania 15236

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Approved:

C. M. Rose

C. M. Rose, Manager
Photovoltaic Pilot Operations

Advanced Energy Systems Division
WESTINGHOUSE ELECTRIC CORPORATION
P. O. Box 10864
Pittsburgh, Pennsylvania 15236

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I. CONTRACT GOALS AND OBJECTIVES

The primary objective of this contract is to investigate high-risk, high-payoff research areas associated with the Westinghouse process for producing photovoltaic modules using non-CZ sheet material. All investigations are being performed using dendritic web silicon, but all processes under study are directly applicable to other ribbon forms of sheet material. The contract is separated into the following tasks.

A. Liquid Junction Technical Feasibility Study

The objective of this task is to determine the technical feasibility of forming front and back junctions in non-CZ silicon using liquid dopant techniques. Numerous commercially available liquid phosphorus and boron dopant solutions are under investigation. Temperature-time profiles to achieve N^+ and P^+ sheet resistivities of 60 ±10 and 40 ±10 ohms per square, respectively, have been established. A study of the optimal method of liquid dopant application is also being performed.

B. Liquid Diffusion Mask Feasibility Study

The objective of this task is to determine the technical feasibility of forming a liquid applied diffusion mask to replace the more costly chemical vapor deposited SiO_2 diffusion mask. Parameters under investigation include liquid applied diffusion masks procured from various vendors, temperature-time profiles of baking liquid masks, film thickness relationship with masking capabilities, identification of etching solutions, process parameters for post-diffusion removal of masks, and methods of liquid mask application.

C. AR, PR Meniscus Coating Application Studies

The objective of this task is to determine the technical feasibility of applying liquid antireflective (AR) and photoresist (PR) solutions using meniscus coating equipment. Film thickness relationships with antireflective capabilities (AR) and masking capabilities (PR) will be investigated, and temperature-time profiles of baking liquid applied solutions for efficient etching techniques will be studied.

D. Ion Implantation Compatibility/Feasibility Study

In this task, the feasibility of producing uniform high efficiency solar cells from non-CZ silicon using ion implantation junction formation techniques will be established. This task will build upon existing information on ion implantation of non-CZ material from other programs and will include:

- An investigation of process variations between processing ion implanted cells and processing gaseous diffused cells using a standard gaseous diffusion process as a baseline;

- Comparison and evaluation of cell efficiencies of ion implanted cells with gaseous diffused cells using a standard gaseous diffusion process as a baseline; and an

- Evaluation of ion implantation parameters such as ion species, energy and dose for front and back junctions, ion implantation angle, annealing method, annealing time and temperature, surface treatment of input non-CZ material, and input non-CZ characteristics including resistivity.

E. Cost Analyses

In this task, SAMICS methodology will be used to quantify production cost improvements associated with process improvements under investigation.

II. SUMMARY

This report describes work performed on JPL Contract No. 955909, "Process Research of Dendritic Web Silicon," during the quarterly period running from September 1, 1982. to November 30, 1982. Technical work in this time period was focused on investigations for liquid diffusion masks and liquid applied dopants to replace the CVD Silox masking and gaseous diffusion operations specified for forming junctions in the Westinghouse baseline process sequence for producing solar cells from dendritic web silicon. JPL contract funds are being used to define evaluate, and report results on experiments discussed in this report; but all technician and material costs are being borne by Westinghouse.

Extensive extended experiments conducted during this reporting period allowed direct comparisons of the baseline diffusion masking and drive processes with those involving direct liquid applications to the dendritic web silicon strips. In these experiments, attempts were made to control the number of variables by subjecting dendritic web strips cut from a single web crystal to both types of operations. Data generated have reinforced earlier conclusions that efficiency levels at least as high as those achieved with the baseline back junction formation process can be achieved using liquid diffusion masks and liquid dopants.

The most recent experiments conducted on this task used liquid boron and SiO_2 solutions obtained from Diffusion Technologies, Inc., have produced results indicating that cell efficiencies may be enhanced with this low cost process. Cell efficiencies as high as 17% were recorded in the first batch of cells processed with liquids received from this vendor. The average cell efficiency of this batch, 14%, was a full percent higher than average cell efficiencies obtained with the baseline process sequence.

During this quarter, tests were conducted which established the feasiblity of substituting a belt furnace for the standard tube type furnaces previously used to drive junctions formed using liquid dopants into dendritic web silicon. This modification could significantly improve the cost effectiveness of the Westinghouse process sequence by reducing equipment costs and improving automatability.

Preparation of dendritic web material for use in ion implantation work to be performed by Spire Corporation under separate contract to JPL was initiated this quarter. In addition, the deliveries of dendritic web sheet material and solar cells specified by the current contract were made as scheduled.

Also in this period, installation of the Kayex-Hamco silicon pellet shot tower which was transferred to this contract was completed. "Shakedown tests" were completed, and several operational runs have been made. Pellets produced in these runs are currently being used as replenishment material in dendritic web growth furnaces being operated at AESD. All efforts associated with the shot tower installation and operation are being completed on a no-cost basis to JPL. Operational data is provided in return for use of the Government owned equipment.

III. TECHNICAL PROGRESS

A. General

Technical work during the past quarter was focused on the first two tasks discussed in Section I of this report: liquid junction and liquid diffusion mask feasibility studies. Investigations on these two tasks are being coordinated with one another in matrix fashion, and results of experiments conducted to date are combined.

The Westinghouse baseline process for fabricating solar cells from dendritic web silicon includes the gaseous diffusion of boron and phosphorus to form the P^+P and N^+P junctions respectively in the N^+PP^+ junction structure. This diffusion process has demonstrated high efficiency cells but requires relatively expensive capital equipment (quartz tube diffusion furnaces) and a multi-step processing sequence. The two diffusion processes are conducted separately, and each is preceded with a chemical vapor deposition (CVD) of an SiO_2 (Silox) mask to allow diffusion in only one surface of the web (front or back) at a time.

The use of liquid dopants as an alternate to gaseous diffusion will reduce solar cell production costs by reducing the amount of chemicals required, by using less expensive capital equipment, by incorporating less involved procedures and controls, and by eliminating several cleaning steps. The use of a liquid precursor to replace the CVD Silox mask would eliminate several clean-up steps associated with the baseline process sequence.

B. Liquid Dopant/Diffusion Mask Verification Experiments

After the period of solar cell processing runs with a liquid dopant source (reported in the previous quarterly report, Westinghouse TME 3158), the Westinghouse Pre-Pilot Facility reverted back to the baseline gaseous diffusion process. The baseline process, presented in detail in previous reports, uses the CVD SiO_2 and gaseous BBr_3 process for the P^+P junction. Data from the cells fabricated using the baseline process were analyzed and are summarized in Table 1. Figures 1 and 2 show the efficiency distribution of two sizes of cells produced during this quarter using the baseline process.

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TABLE 1

SUMMARY OF CELL EFFICIENCY/PROCESS COMPARISONS

Technique	Cell Size cm x cm	# Cells	Average Efficiency %
Baseline Process	1.6 x 9.4	453	12.9
	2.0 x 9.8	343	12.7
*Liquid Boron Liquid SiO_2	1.6 x 9.4	437	12.6
	2.0 x 9.8	481	12.4

*Reported previously in Quarterly Report No. 2 (Westinghouse TME 3158) and given here for comparison with baseline runs.

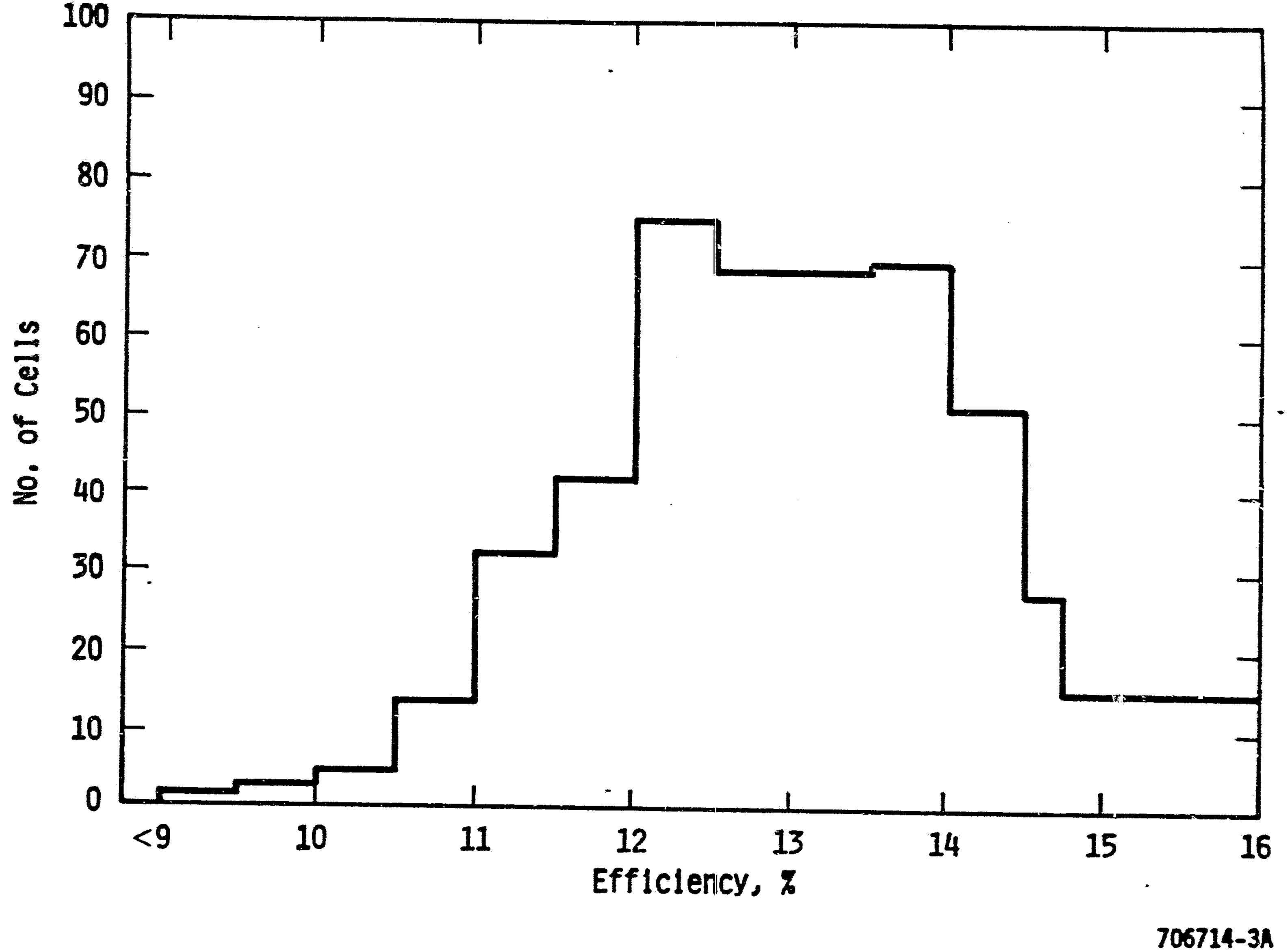

Figure 1. Efficiency Histogram of 1.6 cm x 9.4 cm Cells Fabricated During Current Report Period Using Baseline Process Sequence

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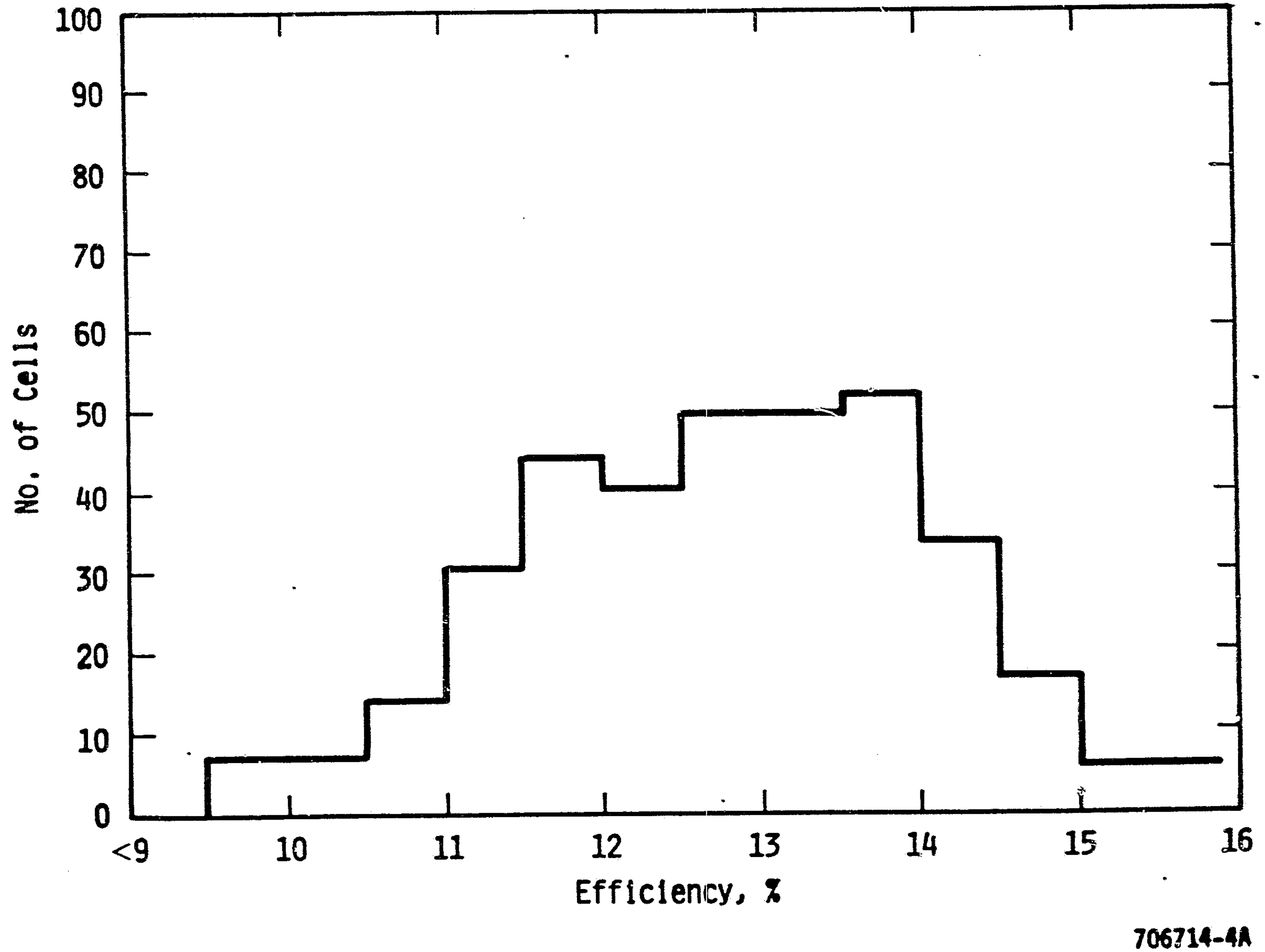

Figure 2. Efficiency Histogram of 2.0 cm x 9.8 cm Cells Fabricated During Current Report Period Using Baseline Process Sequence

On a direct comparison basis, it appears that the baseline cells are slightly higher in efficiency than the liquid dopant cells. However, considering the fact that the liquid dopant process is different and the application method (i.e., hand applicator squeegee) is not optimum, the difference is not considered to be significant.

Therefore, a second series of liquid boron/liquid SiO_2 process runs were initiated. All processing runs were made using a liquid boron diffusant source to prepare the P^+P junction and a liquid SiO_2 diffusion mask for both the boron and phosphorus diffusions. The process sequence used for the second series of liquid dopant experiments is shown in Table 2. During this test period, a B201ET boron source and an SiO_2-700A mask source, both from Filmtronics Company in Butler, PA, were used. All processing runs were made in the Westinghouse AESD Pre-Pilot Facility, and all technician and material costs for these runs were provided by Westinghouse. Table 3 summarizes the data obtained on 9,265 cells fabricated over an extended period using the liquid boron/liquid SiO_2 process. These data are compared to cells processed with the baseline CVD SiO_2/BBr_3 gaseous process. It is instructive to note that there was no significant difference in the average efficiency of cells produced using the two junction formation processes.

This experiment provided statistical verification that the low cost junction formation process could produce cell efficiencies equal to those of the baseline process. However, work completed later in the quarter using liquid boron and liquid SiO_2 solutions from an alternate vendor indicates that a significantly increased efficiency may be feasible with the low cost process. This work is described in a later section of this report.

C. Belt Furnace Feasibility Investigation

An important experiment was conducted to determine the feasibility of using a belt furnace to diffuse junctions in dendritic web strips with liquid dopants applied. A belt furnace of a given capacity is substantially less expensive than the tube-type diffusion furnace specified by the Westinghouse baseline process sequence. In addition, belt furnace operations are inherently more

TABLE 2

PROCESS SEQUENCE FOR FABRICATION OF SOLAR CELLS USING LIQUID BORON AND LIQUID DIFFUSION MASKS

1. Raw web cleaning (including the hot H_2SO_4 treatment).
2. Pre-diffusion cleaning (standard chelating).
3. Paint on liquid SiO_2 on designated N^+ side using a sponge-squeegee.
4. Dry under heat lamp for 5 minutes (about 80°C).
5. Paint on liquid boron dopant on designated P^+ side using a sponge-squeegee.
6. Dry under heat lamp for 5 minutes (about 80°C).
7. Load strips in boat with SiO_2 side facing SiO_2 side and P^+ side facing P^+ side. Pre-bake in oven for 15 minutes at 200°C.
8. Place loaded boat in front end of diffusion furnace and bake strips for 5 minutes at approximately 300°C.
9. Move boat into furnace and diffuse for 30 minutes at 980°C. Slow cool furnace to 700°C at 3°C/minute.
10. Strip oxides in 2:1 H_2O:HF.
11. Repeat Step 2.
12. Paint on liquid SiO_2 on boron diffused side using a sponge-squeegee.
13. Repeat Step 4.
14. Load strips into boat with SiO_2 side facing SiO_2 side.
15. Place boat into front end of $POCl_3$ diffusion tube and bake strips for approximately 300°C.
16. Move boat into furnace and diffuse in gaseous $POCl_3$ for 20 minutes at 850°C (baseline conditions). Slow cool furnace to 700°C for 3°C/minute.
17. Strip oxides and complete baseline process.

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TABLE 3

COMPARISON OF BASELINE PROCESS WITH
LIQUID SIO_2/LIQUID BORON PROCESS

Baseline Process		Liquid SiO_2/Liquid Boron Process	
# Cells	Av. Eff.(%)	# Cells	Av. Eff.(%)
6161	12.6	9265	12.7

NOTES:

1. Period Covered - July 1, 1982 - November 24, 1982
2. Baseline Process - CVD SiO_2 + BBr_3; CVD SiO_2 + $POCl_3$ — See May 1982 Quarterly Report (Westinghouse TME 3150)
3. Liquid Process - Liquid SiO_2 + Liquid Boron; Liquid SiO_2 + $POCl_3$ — See Table 2, this report
4. Data includes cells of different areas (15.7 cm^2; 19.6 cm^2; and 24.5 cm^2) using various vendor's liquid dopants.

continuous, hence, more automatable and cost effective than diffusion furnace operations. Development of a high quality belt furnace junction formation process using liquid dopants could be a benefit to processing virtually all ribbon sheet materials.

For this experiment, which was conducted at the facilities of Radiant Technologies, Inc., at Cerritos, California, a total of 96 strips of silicon web were processed. The JPL contract monitor for the Westinghouse program was present for the diffusion runs made at Radiant Technologies.

Half of the strips were taken to Radiant Technologies, coated with liquid SiO_2/liquid boron, and processed through their belt furnace in four separate runs. The ambients used in these runs were 100% O_2, 50% O_2 and 50% N_2, and pure dry air. The diffusion temperatures were 950°C and 980°C. All diffusions were for 30 minutes with a slow furnace cool to 750°C at 4°C/min. The remaining half of these strips were diffused in the Westinghouse pre-pilot tube type diffusion facility using the liquid SiO_2/liquid boron. These strips were generally crystal pairs of the samples diffused in the belt furnace. Results of the experiment are tabulated in Table 4.

Cells diffused in the belt furnace using the various atmospheres described above yielded similar electrical results; however, cells diffused in a pure O_2 ambient produced the most acceptable appearances in that post-diffusion surface stains were minimized.

In addition to the ambient atmosphere and diffusion temperature variables, the effects of web strip orientation in the belt furnace during diffusion were examined. In each diffusion run, half of the strips were laid flat on quartz plates with the liquid boron side facing upward. The remaining strips were processed in a standing position using a standard diffusion boat. Data are presented in Table 5.

Although some differences are observed, the variations are too small to allow definite conclusions to be drawn. When small variations such as these are

TABLE 4

DATA FROM BELT FURNACE JUNCTION FORMATION EXPERIMENT

1. Overall Results

	Belt Furnace Junction Formation (Liq B/Liq SiO_2)		Tube Diffusion Furnace Junction Formation (Liq B/Liq SiO_2)	
Cell Run #*	No. of Cells	Av. Eff.**	No. of Cells	Av. Eff.**
924-1W	36	12.4	18	12.3
924-24W	18	12.9	25	12.4
924-49W	25	12.8	28	12.5
924-72W	17	12.9	15	12.6

*This cell run number defines the original group of web strips selected for test. Portions of each run were diffused at AESD and at Radiant Technologies, Inc.

**Four cells with efficiencies less than 11% not included in average.

2. Details of V_{oc}, I_{sc}, and FF measurements (averages for all cells)

	V_{oc} (V)	I_{sc} (A)	FF
Processed in Belt Furnace	0.544 ±.010	.578 ±.027	0.780 ±.023
Processed in Tube Diffusion Furnace	0.542 ±.008	.578 ±.028	0.778 ±.029

TABLE 5

EFFECTS OF WEB STRIP ORIENTATION, TEMPERATURE, AND AMBIENT CONDITIONS DURING BELT FURNACE DIFFUSION

Diffusion Conditions		Avg. Efficiency (%)	
Temperature	Ambient	Strip Lying Flat	Strip Standing Up
980°C	100% O_2	13.1	12.6
980°C	50% O_2-50% N_2	13.2	12.6
960°C	50% O_2-50% N_2	12.5	12.9
960°C	Dry Air	12.3	12.7

encountered, it is absolutely necessary to use paired strips from a single crystal to eliminate crystal-to-crystal variations which produce variations of some magnitude.

Although optimum temperatures, ambients, and orientations were not determined from these tests, the feasibility of substituting a belt furnace for the standard tube-type diffusion furnace has been established. If there are performance penalties associated with the use of belt furnaces, the penalties do not appear prohibitive. More statistical data using matched strips from a single crystal will be required to optimize diffusion parameters and to quantify performance differences between the two techniques for driving junctions in dendritic web silicon.

D. Evaluation of Liquid Dopants/Diffusion Masks from Alternate Vendors

Initial data was obtained near the end of this quarter on the liquid solutions obtained from Diffusion Technology, Inc. For this evaluation, the liquid SiO_2 and liquid boron solutions were applied using a sponge squeegee; and the strips were diffused using the sequence previously presented in Table 2 except that the diffusion was carried out at 980°C in a 95% N_2 5% O_2 ambient for 30 minutes. This treatment (suggested by the vendor) produced uniform sheet resistivities of 30 Ω/□ and yielded a clean surface. These strips were then processed through the remainder of the baseline sequence and cells fabricated. Table 6 shows the efficiencies achieved on the first four cells produced using Diffusion Technology liquids. Based on these initial data, which were quite encouraging, a full batch of 24 strips of web was processed using the above-mentioned technique. Results of this run are summarized in Table 7. It is instructive to note that the highest efficiency achieved in this run was over 16%. Figure 3 shows the efficiency distribution of cells produced in this process batch. Based on these data, a series of runs will be made in the upcoming quarter using these solutions to gather a data base and establish the quality of these solutions.

One run was made during this quarter in the Westinghouse pre-pilot facility using the liquid boron BX-10 and liquid SiO_2 undoped glass solutions supplied

TABLE 6

INITIAL DATA FROM CELLS PRODUCED USING LIQUID DOPANTS AND DIFFUSION MASKS PROCURED FROM DIFFUSION TECHNOLOGY

Cell No.	V_{oc} (volts)	I_{sc} (ma)	FF	P_{max} (mw)	η (%)	Cell Size (cm)
2A	0.56	497	0.81	225	14.3	1.6 x 9.8
2B	0.56	506	0.81	229	14.7	1.6 x 9.8
10A	0.54	500	0.78	213	13.6	1.6 x 9.8
10B	0.54	500	0.79	216	13.7	1.6 x 9.8

TABLE 7

DATA ON LIQUID SiO_2/LIQUID BORON CELL PROCESSING RUN USING DIFFUSION TECHNOLOGY SOLUTIONS

Cell Size: 1.6 cm x 9.8 cm

No of Cells: 51

Average Efficiency: 14.0%

Cell Efficiency Distribution

Efficiency Band	No. of Cells	Pct. of Total
>13%	42	82
13-14%	21	41
14-15%	7	14
15-16%	7	14
>16%	4	8

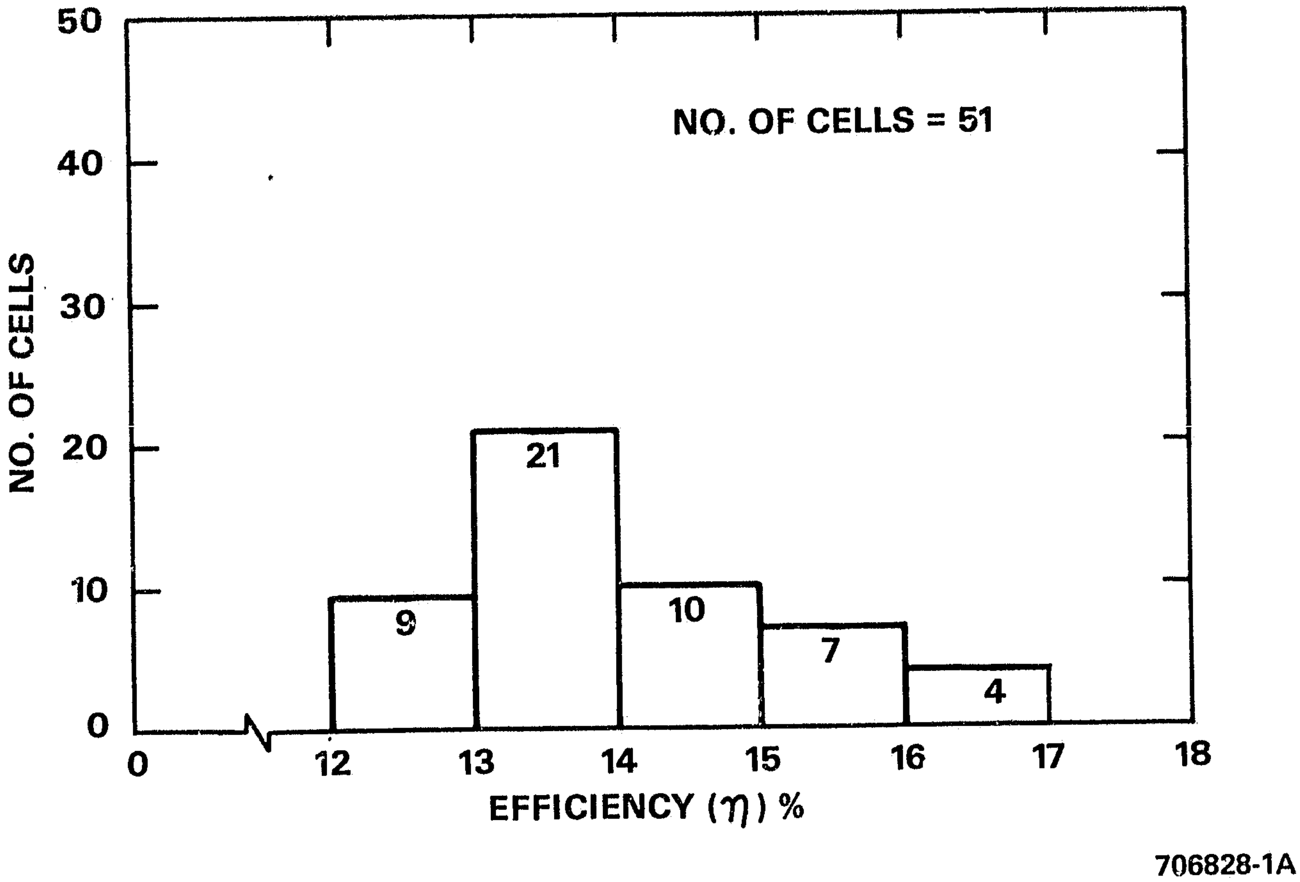

Figure 3. Efficiency Distribution of Cells Processed with Diffusion Technology Liquids

by Allied Chemical. Details of the process are given in Table 2. It was observed after diffusion and stripping that the boron side of the web surfaces were slightly stained. The average efficiency of solar cells tested from this batch, which produced 37 cells, was 13.2%. This is comparable to the efficiencies measured on Filmtronics material and discussed previously. Further runs will be made using Allied Chemical materials in the next period, and arrangements will be made to visit Allied Chemical facilities in Buffalo to discuss the availability, quality control procedures, shelf life, etc., of their solutions.

A cell processing run was made using the "Silicafilm SiO_2" and "Borofilm 100" supplied by Emulsitone, Inc. "Borofilm 100" is a lower cost material and is water based as opposed to all other products tested which were organic based. The procedure used in this run was the same as given in Table 2. The average efficiency of 31 cells produced in this run was 11.8% which is significantly lower than obtained with the baseline process. In addition, there were a large number of cells with efficiencies less than 10% which were not included in the 11.8% average.

An additional processing run will be made to verify these data; and in addition, several runs will be made using the organic based Emulsitone liquid boron. These data should indicate the feasibility of using a water based dopant.

E. Dark I-V Measurements on Liquid Boron/Liquid Phosphorus Cells

Dark I-V measurements were made on two all liquid (boron and phosphorus) cells during this quarter. Lighted I-V data for these cells were reported in the last quarterly report (Westinghouse TME 3158, Page 25). Table 8 shows the dark I-V data together with previous reported lighted data for comparison. The low values of J_{02} obtained indicate good quality junctions, but the I_{sc} values are lower than are routinely achieved with cells processed using gaseous $POCl_3$.

TABLE 8

DARK I-V MEASUREMENTS ON LIQUID JUNCTION SOLAR CELLS*

Cell ID	Cell Area cm^2	T Bulk** μsec	J_{sc} ma/cm^2	V_{oc} Volts	Fill Factor	η %	Series Resistance Ω-cm	Shunt Resistance $kΩ-cm^2$	J_{02} A/cm^2
60A	15.04	21	27.4	0.54	0.76	11.29	0.289	17	4.1×10^{-7}
91A	15.04	9	26.2	0.53	0.71	9.94	0.292	0.42	1.3×10^{-5}

*Both cells produced using Emulsitone liquid boron and liquid phosphorus solutions.

**The bulk lifetime calculated from the dark I-V measurements cannot be directly compared to the OCD lifetime. It is, however, a good relative measure of cell quality.

Figures 4 and 5 show the dopant profiles for the N^+P and P^+P junctions on two all liquid doped cells as determined from the spreading resistance data. It should be noted that the junction depth of the N^+P junction of cell 60A is 0.66 μm as compared to 0.25 μm with the $POCl_3$ process. This explains the lower J_{sc} values obtained in dark I-V measurements on this cell. Cell 91A had a N^+P junction depth of 0.48 μm.

These data indicate that (1) that the method of application, i.e., with sponge squeegee, did not give a sufficiently uniform and controlled thickness, and (2) that the diffusion temperature was too high. Further work will be done in the next quarter with liquid phosphorus junction formation using the meniscus coater.

F. Meniscus Coating Liquid Application Studies

Experiments conducted earlier this year indicated that liquids used in dendritic web processing for front and back junctions, diffusion masks, antirelfective coatings, and photoresist films could be most uniformly applied using a meniscus coater (ref. Westinghouse TME 3150, Quarterly Report No. 1, May 31, 1982). The operation of this device is described in the MEPSDU Summary Technical Report (Westinghouse TME 3149, July 1982).

Accordingly, a meniscus coater ("CAVEX" unit) was placed on order from Integrated Technologies using Westinghouse capital funds. This device will be used to expand the boron liquid dopant work to the phosphorus junction formation in which manual application techniques have been shown to be unsatisfactory.

An equipment verification test was held at Integrated Technologies in October. Several operational problems were identified during the test, which was overseen by a Westinghouse test engineer. These problems were subsequently corrected by the vendor, and the final acceptance test was held the second week of November. Problems were eliminated by modifications to the carriage drive mechanism and installation of a new vacuum chuck. The vacuum chuck to applicator head alignment was pre-set, and the meniscus came into contact with 100% of the chuck area on all test runs. The test runs were carried out using the Westinghouse antireflective coating solution. The results of the coating tests are given

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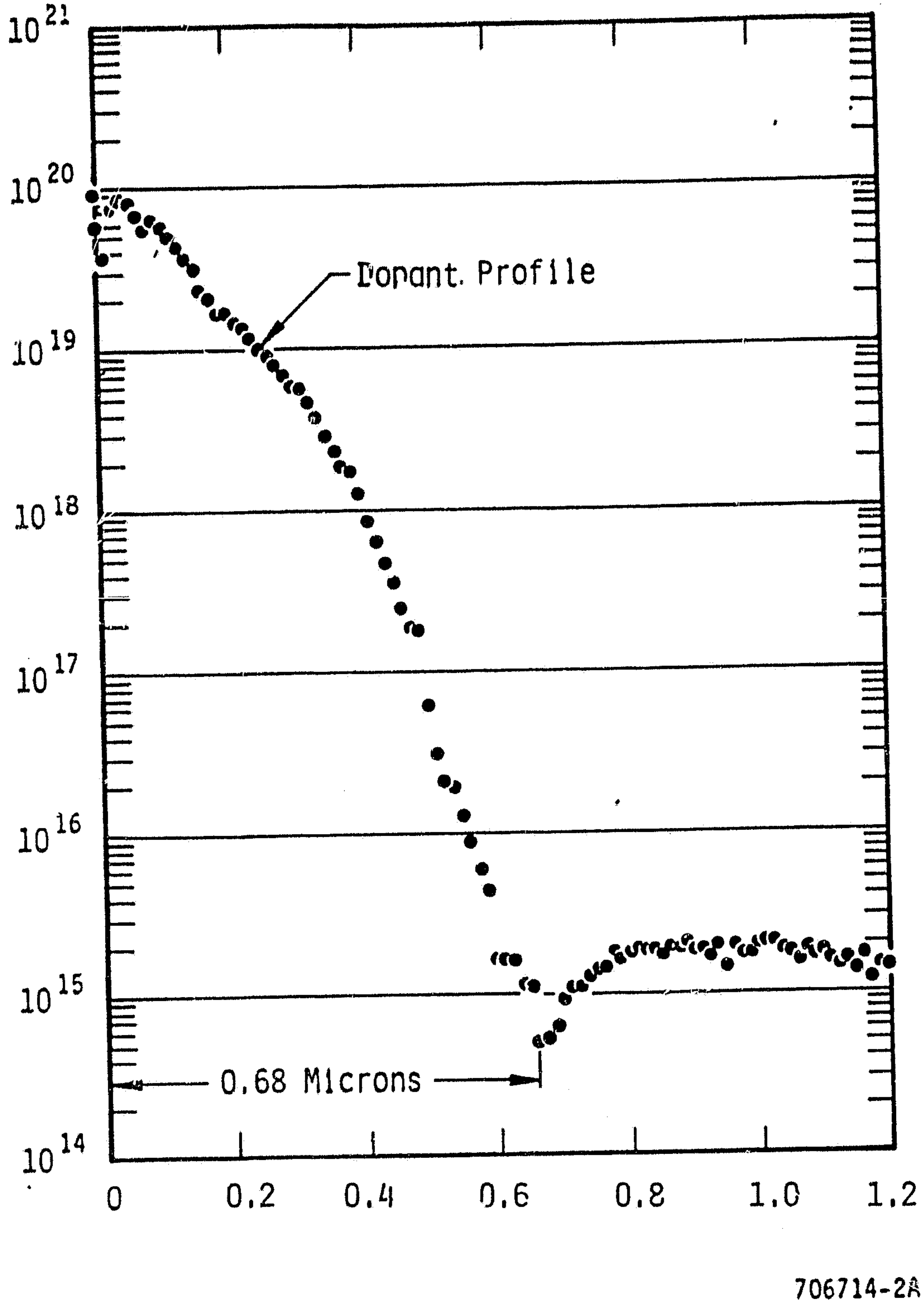

Figure 4. N^+P Junction Profile in Liquid Diffused Cell #60A

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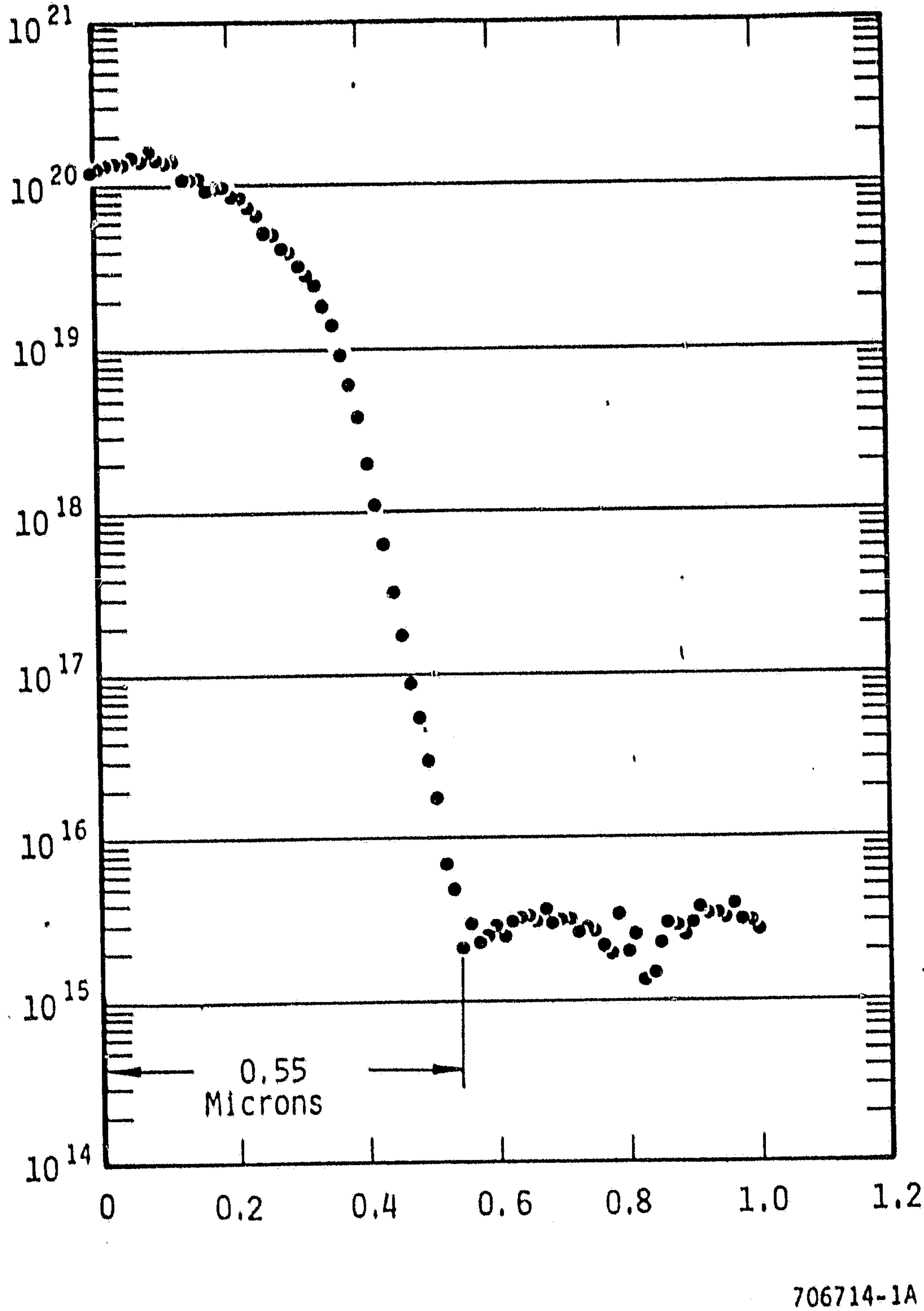

Figure 5. $P^{+}P$ Junction Profile in Liquid Diffused Cell #60A

in Table 9. Acceptable results were achieved at application speeds up to 25"/min, and combination of solution viscosity and applicator speed permit application of a uniform coating of acceptable thickness.

After completion of qualification tests, the meniscus coater was packaged for shipment to Westinghouse. The unit is scheduled to arrive during the first week of the next reporting period.

G. Ion Implantation Compatability/Feasibility Study

Work was initiated in this quarter on the task to determine feasibility of producing uniform high efficiency solar cells from non-Cz silicon using ion implantation junction formation techniques (Item D, Section I of this report).

The first phase of this work requires preparation of dendritic web sheet material suitably sized for ion implantation. Accordingly, 100 pieces of dendritic web material were grown on the AESD web growth furnaces and cut into 2.1 cm x 5.0 cm blanks. These blanks have been shipped to JPL. Actual ion implantation of the material will be performed by Spire Corporation for JPL under separate contract.

H. Silicon Shot Tower

In July 1982, a silicon shot tower which was developed for JPL by Kayex Corporation under subcontract to Union Carbide Company was transferred to this contract. The transfer was made on a "no-cost" basis to JPL. The purpose of the transfer was to facilitate an evaluation of dendritic web silicon grown from small Si pellets produced by the shot tower. This evaluation will be made by processing dendritic web grown from shot into cells both at Westinghouse and at JPL.

The initial phase of this effort was completed by Kayex Corporation under Westinghouse contract. A Westinghouse engineer visited Kayex, took pictures of the shot tower, witnessed critical component disassembly operations by Kayex personnel, and obtained drawings and operational manauls. After disassembly, the unit was shipped to Westinghouse AESD in Pittsburgh.

TABLE 9

COATING TESTS USED TO QUALIFY MENISCUS COATER

No.	No. of Pieces	Speed	Color After 10 min. Bake
1	3	25"/min	purple/blue (acceptable)
2	3	20"/min	dark purple (too thin)
3	3	20"/min	dark purple (too thin)
4	2	20"/min	purple/blue (acceptable)
5	4	25"/min	purple/blue (acceptable)

During this quarter, the shot tower was re-installed at AESD in a building capable of handling the unit's 40 foot long drop tube. Figure 6 is a photograph of the shot tower after installation. The heated zone of the device is located on the upper platform. Also visible in the forefront of the photograph is the RF power supply. The drop tube extends from the bottom of the heated zone downward to the floor of the building. The tube continues through a hole in the floor into a pit. A 10 foot extension tube was added to the lower end of the drop tower at the recommendation of Kayex personnel. Neither the bottom of the drop tube nor the shot collection basis are visible in the photograph.

After connection of water, electrical, and gas lines to the unit, shakedown operations were initiated. Several modifications, incorporated to improve controls and to reduce the operating accoustical noise level from the extremely high levels reported by Kayex-Hamco to acceptable levels, proved to be more than adequate.

Initial shotting run attempts were unsuccessful due to water leaks in the system or freezing of the silicon in the crucible nozzle. The following changes were made to correct conditions observed during these shakedown runs:

1. The length of the crucible nozzle was reduced to prevent silicon freezing.

2. Wherever possible, all coolant connections were moved from inside the capacitor bank to the outside. High pressure, high temperature hose was used to replace the reinforced Tygon tube previously used.

3. Helium flow was reversed so as to enter at the top of the drop tube and exit from the collection tank.

4. The operating procedures were modified to run the heat-up part of the cycle with static helium in the drop tube until shotting begins.

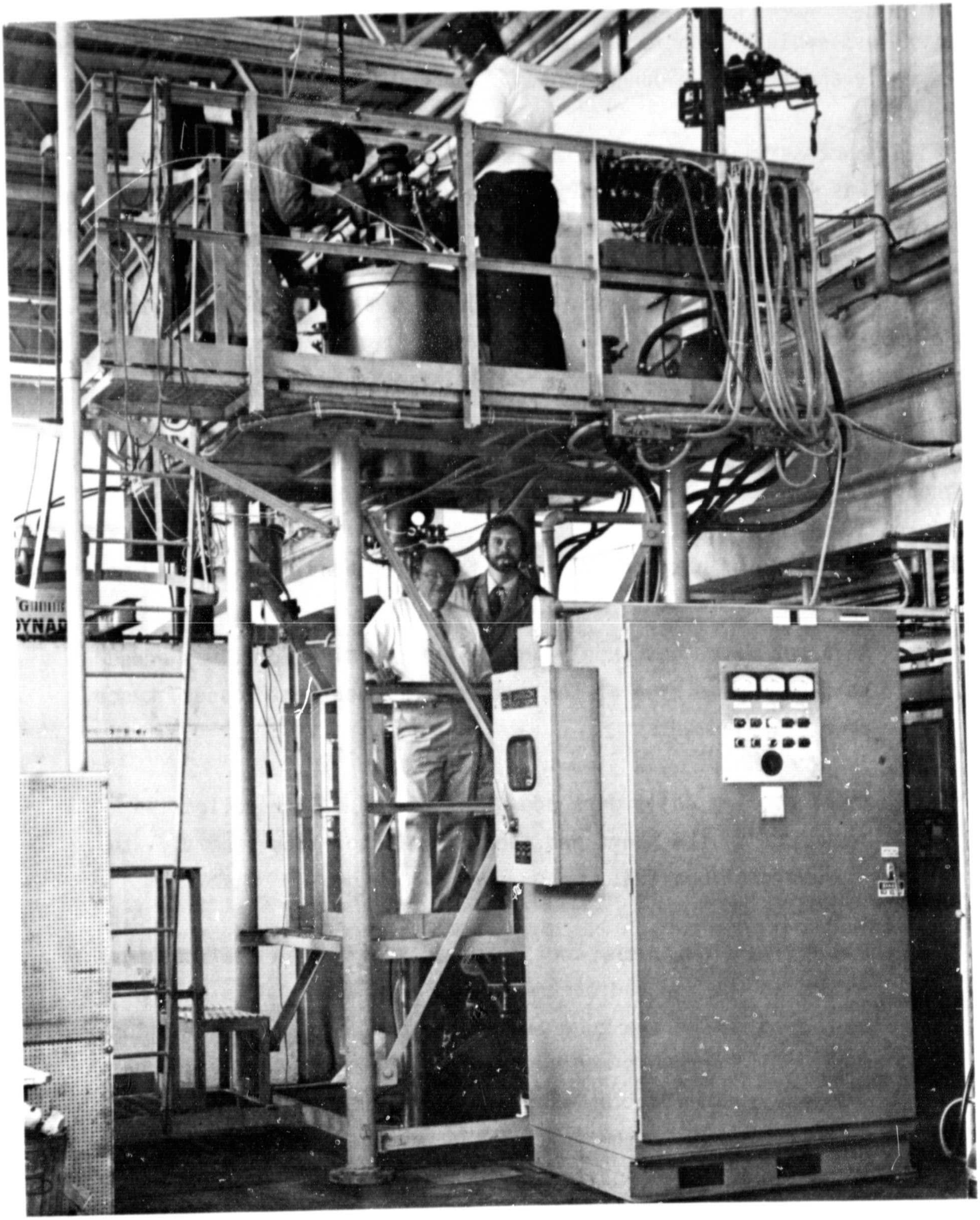

Figure 6. Silicon Pellet Shot Tower After Assembly at Westinghouse

A Kayex test engineer who is shown in the photograph assisted and supervised in assembly and shakedown operations.

The first successful shotting run was made in late September. After shotting began, it was found to be necessary to provide a pressure drop between the furnace section of the system and the shot tube in excess of 1 psi to maintain the mölten silicon flow in a steady stream. The pressure drop was maintained between 1.3 and 1.8 psi and appeared to yield shot of the proper diameter. It is apparent that shot size can be altered by manipulating the pressure drop, but only within narrow limits.

The run yielded 2350 grams of what appears to be good shot. Input material weighed 2523 grams, resulting in a net yield of 94%.

Prior to initiation of a second run, the following additional system modifications were made.

1. An argon cover gas supply and graphite wool blanket was added to the furnace area of the system to reduce heat losses, hence, power requirements.

2. Water cooling coils were added to the top of the collection drum, and to the short end tube of the shot tube assembly, to improve shot cooling.

3. The helium flow in the shot tube was modified so that cool gas enters at the top and bottom of the drop tube and is exhausted at the center of the tube and at the bottom of the collection tank. This produces additional cooling in the tube required to complete solidification of pellets prior to contact with the collection tank. (The initial run produced evidence that many of the pellets had not totally solidified prior to impact in the collection tank.)

4. An oxygen monitor and hygrometer were installed in the system to allow monitoring and recording of oxygen and water vapor levels prior to initiating a shotting run.

5. A Grafoil radiation shield was installed to replace the molybdenum shield in the furnace area of the shot tower, thereby eliminating potential molybdenum contamination of the silicon produced.

After completion of modifications, a second production run was made. This run produced 2325 grams of silicon shot (92% yield) made up as follows: 530 grams over 2 mm diameter; 1450 grams from 1 to 2 mm dia.; 215 grams from .6 to 1 mm dia.; 130 grams less than .6 mm dia. During the run it became obvious that the operator can impose a considerable influence on shot size by varying the pressure drop across the furnace chamber and the shot tube receiver section.

While the product of this run appeared acceptable, further system changes were implemented to assure shotting at a lower temperature. Data indicated that the nozzle temperature at the exit end was significantly lower than the temperature of the melt and that the silicon coming through the orifice was too cold for optimum flow. Thus the crucible nozzle was further reduced in length so that it ends inside the cavity provided in the susceptor, rather than being flush with it as in the original configuration.

A significant operational modification was also incorporated. To improve shot purity, the system is currently being evacuated to .07 psi before backfilling with gas. This not only reduces the amount of free oxygen in the system but also reduces the water content. To extend the anti-oxidant protection, the system is filled with argon before removing the furnace lid.

A sufficient quantity of high purity, 0.6 to 2 mm, silicon shot has been made in the shot tower to initiate growth runs in which silicon shot is automatically introduced into the melt as dendritic web crystals are being withdrawn from web growth furnaces at AESD. These growth runs, started during the last two weeks

of November, are being made to evaluate the response of two different furnace lid and shield configurations to the feeding mode of operation, to acquaint the web growers with the set up and operation of the furnaces in the feeding mode, and to identify areas for further development in order to consistently sustain continuous crystal growth. Dendritic web produced during these runs is being combined with standard production web for processing into cells. When the data on cell performance becomes available, it is expected to be an indicator of the quality of the output of the silicon shot tower.

IV. ACTIVITIES PLANNED FOR NEXT QUARTERLY PERIOD

The following activities are planned for the next quarterly reporting period covering the time span from December 1982 through February 1983.

1. Collect and analyze data on recent solar cell processing runs using the baseline process sequence.

2. Initiate another period of extended liquid boron/liquid SiO_2 processing runs to build up a data base using Diffusion Technology solutions.

3. Continue study of Emulsitone and Allied Chemical solutions.

4. Expedite delivery of meniscus coating machine and initiate investigation of liquid phosphorus junction formation.

5. Complete evaluation of dendritic web grown from pellets produced in initial shot tower runs.

V. PROGRAM DOCUMENTATION

All programmatic documentation specified in the Westinghouse Process Research of Non-CZ Silicon Material MEPSDU contract has been submitted in accordance with schedular requirements. A list of the programmatic documentation and submittal dates is compiled in Table 10.

TABLE 10

PROGRAM DOCUMENTATION SUBMITTAL STATUS

Item	Submittal Date
1. Monthly Technical Reports	
A. March 1982	April 1, 1982
B. April 1982	May 3, 1982
C. May 1982	June 3, 1982
D. June 1982	July 8, 1982
E. July 1982	August 2, 1982
F. August 1982	September 7, 1982
G. September 1982	October 7, 1982
H. October 1982	November 8, 1982
I. November 1982	December 6, 1982
2. Financial Management Reports	
A. March 1982	April 6, 1982
B. April 1982	May 19, 1982
C. May 1982	June 14, 1982
D. June 1982	July 16, 1982
E. July 1982	August 16, 1982
F. August 1982	September 14, 1982
G. September 1982	October 15, 1982
H. October 1982	November 15, 1982
I. November 1982	December 15, 1982
3. Program Plan, Cost Estimates, & WBS	
A. Original	March 12, 1982
B. Revision	May 26, 1982
4. MEPSDU Summary Report	
A. Draft	June 3, 1982
B. Final	July 26, 1982